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ENERGY EFFICIENT CITY IN MALAYSIA
WIND FLOW IN NEIGHBORHOOD AREAS

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Abstract

It is time for the countries in Southeast Asia to take concrete action in order to tackle global warming all over the world. This paper discusses planning guidelines of neighborhood areas in consideration of wind flow in Malaysia from the following two aspects. Firstly, the effects of natural ventilation on energy saving among households are examined through a questionnaire survey. Secondly, this paper investigates physical wind environment in the same case study areas through wind tunnel tests. It aims to help achieve energy efficient cities in Southeast Asian countries as well as Malaysia.

Keywords: Energy efficient city, Wind flow, Residential neighborhood, Wind tunnel tests

1. Introduction

It is said that the influences of global warming have been gradually appearing in many regions of the world. The Kyoto Protocol on climate change has effectively come into force in February 2005. This requires the signatories to reduce emissions of the greenhouse gases below 1990's level by the year 2012 in order to contribute toward a more sustainable global environment. The reductions of greenhouse gases are required only for the developed countries so far. However, it can be predicted that developing countries will be required to consent to the Protocol in the near future. Thus, it is important and effective to consider the energy saving means in developing countries in the course of its economic development.

The world oil price hike can be taken as another aspect. The world crude oil price has been continuing rise in recent years. This would badly affect Southeast Asian economies as a shortage of oil or the inflation etc. Therefore, it is important to improve energy efficiencies in every sector and reduce the dependence on fossil fuels in order to maintain a stable economic growth.

The emission cut of greenhouse gases caused by the use of air-conditioners in residential areas as well as the reduction of dependence on fossil fuels could be efficiently carried out through energy saving efforts by maximizing the use of natural ventilation. Most Southeast Asian cities experience hot and humid climate during most part of the year. Thus, natural ventilation can be one of the most effective energy saving methods to maintain a reasonable thermal condition in dwelling units.

A number of studies related to natural ventilation in buildings can be seen over the last few decades (e.g. Backer and Standeven, 1996; Raja and Humphreys et al., 2001). However, there are relatively few studies on wind flow in larger areas such as neighborhood areas. Wind flow in neighborhood areas strongly affects the air change rate of natural ventilated buildings. Moreover, wind flow plays an important role to diffusing air pollutants and heat at the urban level as well as the neighborhood level.

This paper discusses planning guidelines of neighborhood areas in consideration of wind flow in Malaysia from the following two aspects. Firstly, the effects of natural ventilation on energy saving in households are examined through a questionnaire survey.

Secondly, this paper investigates physical wind environment in the same case study areas through wind tunnel tests. It aims to help achieve energy efficient cities in Southeast Asian countries as well as Malaysia.

2. Questionnaire survey on behavior for natural ventilation in terraced houses

2.1. Methods

Johor Bahru Metropolitan City is located in the southernmost part of Peninsular Malaysia. It is the second largest city after Kuala Lumpur and its population size including the conurbations is approximately one million in 2000. According to the property market report (Malaysia, 2002), terraced houses accounted for around 57% of the total existing housing stock of Malaysia in 2002, followed by apartment houses (25%) and detached houses (11%). Thus, a large majority of housing types in Malaysia are considered as terraced houses. For this reason, this study has been focusing especially on terraced houses. Three typical neighborhood areas in Johor Bahru City, which are mainly composed of terraced houses, were chosen for this survey.

A questionnaire survey was designed to extract information from occupants mainly under the following categories.

(1) Frequency and duration of open windows: the frequency and time periods when the occupants open their windows per day. The main reason why they do not open their windows.
(2) Frequency and duration of operating air-conditioners: the ownership of air-conditioners. The frequency and time periods when the occupants use air-conditioners.
(3) Frequency and duration of operating ceiling fans: the ownership of ceiling fans. The frequency and time periods when the occupants use ceiling fans.
(4) Electricity consumption: the mean monthly electricity fee and its consumption. Significant factors to influence the household electricity consumption.

This survey was carried out on every Saturday from 4 September to 9 October 2004. The questionnaire consisted of 26 questions and requirements. The letters of asking for cooperation to the survey were distributed to approximately 820 households in three selected neighborhood areas at random. After three or four days, the surveyors visited the above households and interviews were made using the questionnaire sheet. There were available supports for the survey from 366 respondents who were mainly housewives. Thus, the respondent rate was approximately 45%.

2.2. Profile of respondents

Malaysians mainly consists of three ethnic groups, i.e. Malay, Chinese and Indian. The proportion of these ethnic groups in this survey was quite similar with national approximate average; 64% of respondents were Malays, 28% were Chinese and 7% were Indians, respectively. The average household size of respondents were 5.4. They had an average of 2.1 workers and 2.4 children in household.

An approximately 78% of respondents owned their houses, while 22% rented their houses. Majority of housing type was terraced house (88%), followed by semi-detached house (9%) and bungalow (3%). The house buildings consisted with 40% of single and 60% of two story heights and had an average of 3.5 bedrooms. The average site area per dwelling was 198m^2 and total floor area was 143m^2.

2.3. Usage of windows and cooling appliances

Fig.1 shows the frequency of respondents who open their windows at respective hour during the day. Since the purpose of this question was to examine general situations of open windows in the whole dwellings, it did not specify particular rooms, e.g. living room, bedrooms etc. The result shows that nearly 80% of respondents usually open their windows during the daytime from 9am to 6pm. It is argued that the night ventilation is especially effective to improve thermal conditions in brick houses like these Malaysian terraced houses, which have a large heat capacity. However, the frequency of open windows dropped to around 10% during the nighttime as indicated in Fig.1.

The mean duration of open windows per average day was about 12 hours. Fig.2 illustrates the main reasons for not opening windows. An approximately 38% of respondents answered ‘insects’ as the main reason, followed by ‘security (35%)’, ‘rain (22%)’, ‘dust (18%)’ and ‘air-conditioners (13%)’ etc.

Nearly 62% of respondents owned at least one air-conditioner in this survey. The results showed that there is a significant relationship between mean monthly household income and number of air-conditioners among households. It indicated that the more monthly income they earn, the more air-conditioners they have. Therefore, it can be implied that the air-conditioner ownership is expected to further rise according to economic growth in the near future, if they do not consider proper energy saving.

The average number of air-conditioners among their owners was 2.3 units per household. They have installed them in the master bedroom (95%), other bedrooms (58%), living room (28%) and dining room (3%). It can be inferred from this result that since most air-conditioners had been installed in their bedrooms, most respondents use air-conditioners as a cooling appliance for sleeping.

Fig.3 illustrates the hourly frequency of respondents who operate air-conditioners during the day. Only around 10% of their owners operate air-conditioners during the daytime. However, its percentage rapidly rose during the evening from 7pm and it reached 84% at midnight. It is noted that more than 50% of their owners continue to use air-

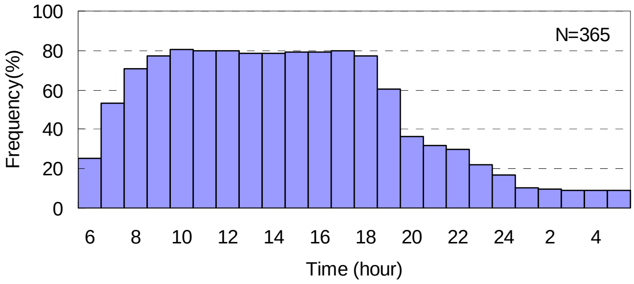


Fig.1. Frequency of open windows during the day (average day)

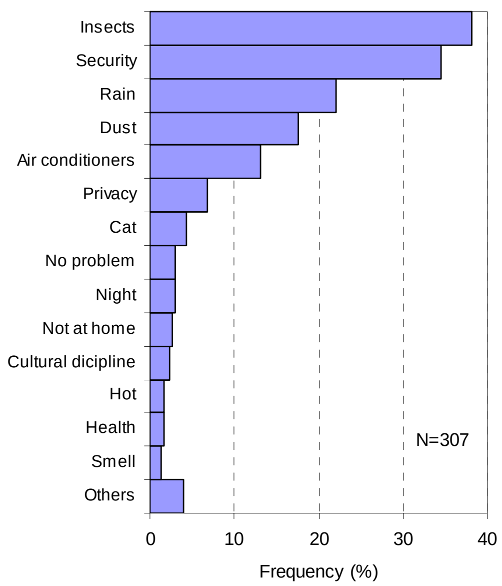


Fig.2. Reasons for not opening windows

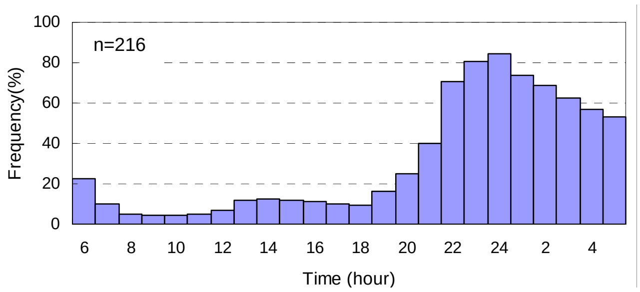


Fig.3. Frequency of operating air-conditioners during the day (average day)

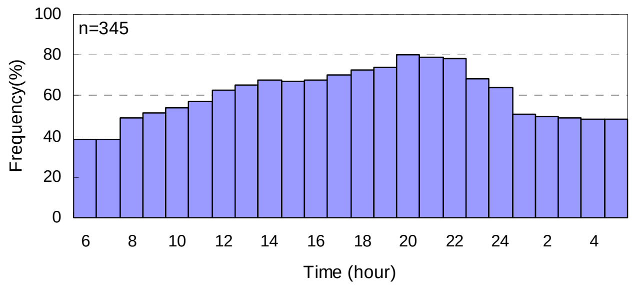


Fig.4. Frequency of operating ceiling fans during the day (average day)

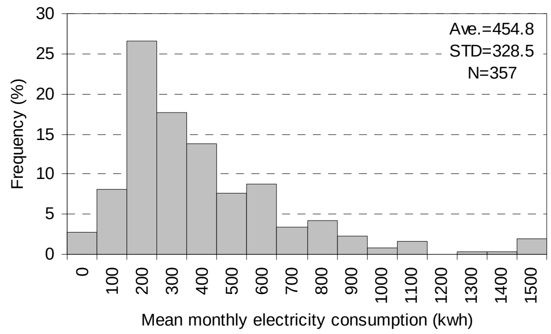


Fig.5. Mean monthly electricity consumption among households

Table 1. Correlation coefficients between selected variables and mean monthly household electricity consumption

	Variables	Correlation coefficient (R)	Significance level of t	Significant (at 1% level)
1	Number of air-conditioners	0.55	0.00	S
2	Duration of operating air-conditioners	0.52	0.00	S
3	Number of water heaters	0.45	0.00	S
4	Household income	0.39	0.00	S
5	Site area	0.37	0.00	S
6	Number of bedrooms	0.30	0.00	S
7	Building area	0.30	0.00	S
8	Total floor area	0.29	0.00	S
9	Number of ceiling fans	0.29	0.00	S
10	Household size	0.24	0.00	S
11	Duration of operating ceiling fans	0.18	0.00	S
12	Duration of staying home	0.11	0.05	NS
13	Duration of open windows	-0.03	0.53	NS

S=significant; NS=not significant

Table 2. Coefficients of variables included in regression equation

Independent variables	Unstandardized coefficient	Standardized coefficient	Significant
x_1: Number of air-conditioners	78.01	0.362	S**
x_2: Duration of operating air-conditioners	39.75	0.419	S**
x_4: Household income	0.0166	0.173	S**
x_5: Site area	0.305	0.114	S*

S*=significant at 5% level; S**=significant at 1% level

conditioners during the whole nighttime until 5am. The authors inferred that most respondents used air-conditioners as a cooling appliance for sleeping. The above results (Fig.3) support this inference. The mean duration of operating air-conditioners per average day was about 7.6 hours.

Nearly 98% of respondents owned ceiling fans in this survey. The average number of ceiling fans among their owners were 3.9 units per household. They have installed them in the living room (96%), master bedroom (78%), other bedrooms (66%) and dining room (41%).

Fig.4 illustrates the hourly frequency of respondents who operate ceiling fans during the day. The frequency was relatively high throughout the day. Especially during the evening from 8pm to 10pm, the percentage rose to almost 80% as indicated in Fig.4. Then, its percentage recorded still 40-50% during the nighttime. The duration of operating ceiling fans was relatively long. It was found that nearly 16% of their owners used ceiling fans during 24 hours. The average operating hour was about 15; this was much longer than that of air-conditioners (7.6 hours).

2.4. Electricity consumption among households

Fig.5 indicates the mean monthly electricity consumption among respondents. The average value of mean monthly electricity consumption among households was 454.8kwh in this survey.

Table 1 indicates results of correlation analysis between selected variables and mean monthly household electricity consumption. The highest correlation coefficient by 0.55 was obtained between 'number of air-conditioners' and 'household electricity consumption' in this survey, followed by 'duration of operating air-conditioners (0.52)', 'number of water heaters (0.45)', 'household income (0.39)', 'site area (0.37)' and 'number of bedrooms (0.30)' etc. It is found that there is a relationship particularly between the variables concerning air-conditioners and household electricity consumption.

In order to illustrate further determinants of mean monthly household electricity consumption, a multiple regression analysis was attempted. The independent variables included in the regression equation were the variables, which were found to be highly correlated and significantly related with household electricity consumption in Table 1.

According to the regression equation, the coefficient of determination (R^2) was 0.53. Thus, more than 53% of the spatial variation of mean monthly household electricity consumption to the case study areas can be explained by the model. This means that four explanatory variables, i.e. 'number of air-conditioners', 'duration of operating air-conditioners', 'household income' and 'site area', fit the model well and they are in fact good predictors of mean monthly household electricity consumption in the case study areas.

Table 2 shows coefficients of respective independent variables in the regression equation. The standardized coefficient was the highest in 'duration of operating air-conditioners (0.42)' at 1% significant level, followed by 'number of air-conditioners (0.36)', 'household income (0.17)' and 'site area (0.11)'. This indicates that the reduction of both numbers and use of air-conditioners are the most effective means for achieving electricity saving among households.

2.5. Discussion

'Air-conditioners have huge impact on the whole household electricity consumption'

The results showed 62% of respondents owned an average of 2.3 air-conditioners. The significant relationship was found between 'mean monthly household income' and 'number of air-conditioners'. Thus, it could be implied that the air-conditioner ownership is expected to further rise according to continuing rise in household income in the near future. The multiple regression analysis revealed that four explanatory variables, i.e. 'number of air-conditioners', 'duration of operating air-conditioners', 'household income' and 'site area', were good predictors of mean monthly household electricity consumption in the case study areas. Moreover, the results indicated that the reduction of both numbers and use of air-conditioners were the most effective means for achieving electricity saving among households.

'Importance of night ventilation'

The authors assumed that the occupants who frequently open their windows would use less air-conditioners, thus it would contribute to reduce household electricity consumption. However, the significant relationship could not be seen between 'duration of open windows' and 'duration of operating air-conditioners' in this survey; correlation coefficient between them was only 0.18. Most respondents opened their windows mainly during the daytime especially from 9am to 6pm as indicated in Fig.1. By contrast, many air-conditioner owners used them during the nighttime especially from 10pm to 5am as shown in Fig.3. Hence, this indicates that most respondents open their windows during the daytime regardless of the air-conditioner ownership and close their windows during the nighttime. In other words, it can be concluded that these usage patterns of windows and air-conditioners do not overlap during the day regardless of the air-conditioner ownership. Therefore, it is very important to encourage both air-conditioner owners and non-owners to open windows especially during the nighttime for achieving energy saving objectives.

'How can we encourage occupants to open windows?'

'Insects' was recorded as the most significant reason for not opening windows. However, this survey showed although nearly 90% of respondents had installed window grilles for security purpose, only 1% had installed insects screen on their windows. Hence, it can be suggested that to install the insects screens at the construction phase of the dwellings would be one of the important means to encourage occupants to open their windows.

Moreover, it was found from respondents' free comments that many burglar cases were taking place frequently in the case study areas. Security issue was considered one of crucial problems in these areas. Further improvement of security in residential areas was also strongly required in order to make residents feel safe and encourage them to open their windows more. Furthermore, the results indicated that the awareness of respondents towards energy saving for sustainable global environment was not necessarily high at the moment. Needless to say, it is essential to enhance the public awareness towards global environment in order to achieve energy saving objectives in cities.

3. Wind environment evaluation of neighborhood areas

3.1. Results summary of wind tunnel tests

The previous studies (Kubota and Supian, 2004, 2005) presented results of the wind tunnel tests on selected neighborhood areas in Johor Bahru City, Malaysia. The main aim of the wind tunnel tests was to examine relationship between housing patterns and the mean value of wind velocity at the neighborhood level.

The wind tunnel tests were conducted on the same neighborhood areas, which aimed in the above questionnaire survey. The selected five case study areas and the measuring points (1.5m height in actual scale) for the previous wind tunnel tests are shown in Fig.6.

The results of the above study showed that there is a strong relationship between the gross buildings coverage ratio and the mean value of wind velocity ratio of the cases (Fig.7). The results also indicated that the mean values of wind velocity ratio of the Malaysian five cases were slightly higher than the trend line of Japanese apartment cases.

3.2. Methods of evaluation

The following two steps were considered in wind environment evaluation. Firstly, the wind velocity ratios measured in the previous wind tunnel tests, were transformed into actual wind velocities by using climatic data of selected major towns of Malaysia. Secondly, the wind environment of the five terraced houses cases and the Japanese cases was evaluated under respective climatic conditions using the following criteria.

Murakami and Morikawa (1985) proposed the range of reasonable wind speed for avoiding thermal discomfort due to insufficient wind speed in summer as well as the problems caused by strong wind. Since it was found that the limits of reasonable wind speed range changed according to the increase of outdoor air temperature especially under weak wind conditions, the proposed criteria were taken into account of the temperature effect. The present study discusses the planning guidelines of neighborhood areas in which wind velocity is usually reduced by the effects of buildings density. Thus, the above criteria were applied to the evaluation of wind environment shown below.

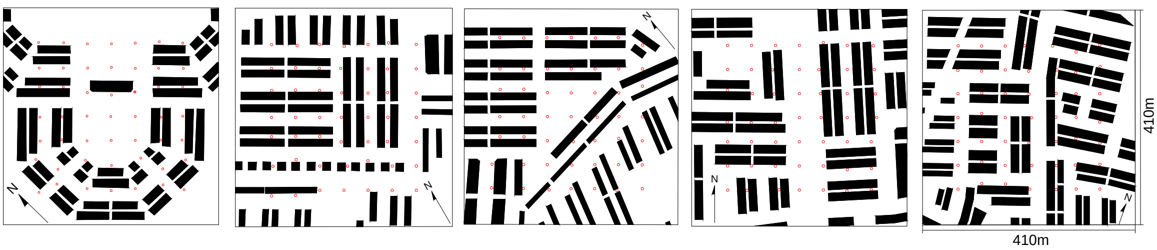


Fig.6. Case study areas in previous wind tunnel tests
Source: Kubota and Supian (2004,2005)

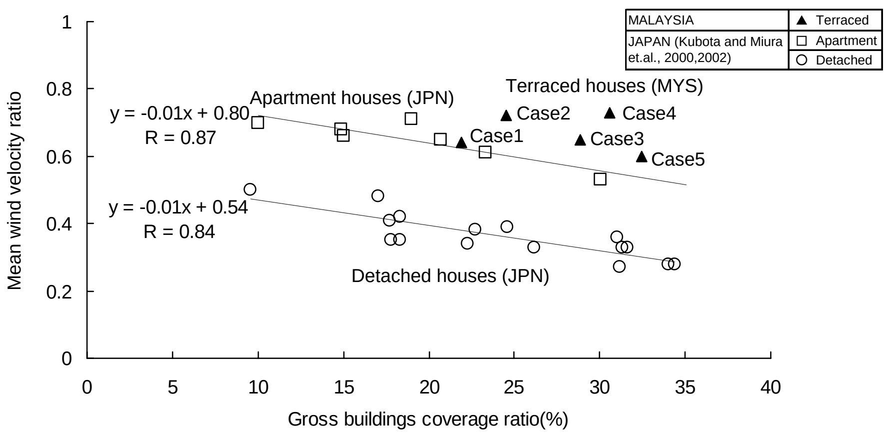


Fig.7. Relationship between gross buildings coverage ratio and mean wind velocity ratio
Source: Kubota and Supian (2005), Kubota, Miura, Tominaga and Mochida (2000, 2002)

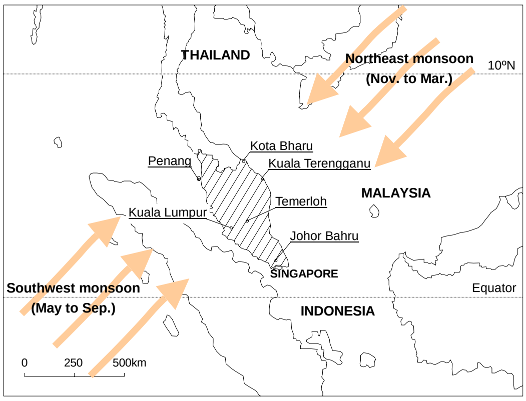


Fig.8. Case study towns for wind environment evaluation

3.3. Climatic conditions in Malaysia

The six towns in Peninsular Malaysia, Penang, Kuala Lumpur, Johor Bahru, Temerloh, Kota Bharu and Kuala Terengganu were selected as case study towns for the present wind environment evaluation. Fig.8 illustrates the location of selected six towns and general wind directions of each monsoon season.

In Malaysia, both the mean temperature and mean relative humidity do not vary throughout the year very much. Nevertheless, the direction and mean velocity of wind in the respective towns are different between monsoon seasons. The mean wind velocities in the six towns indicated 1-3m/s according to the climatic data over the past 15 years.

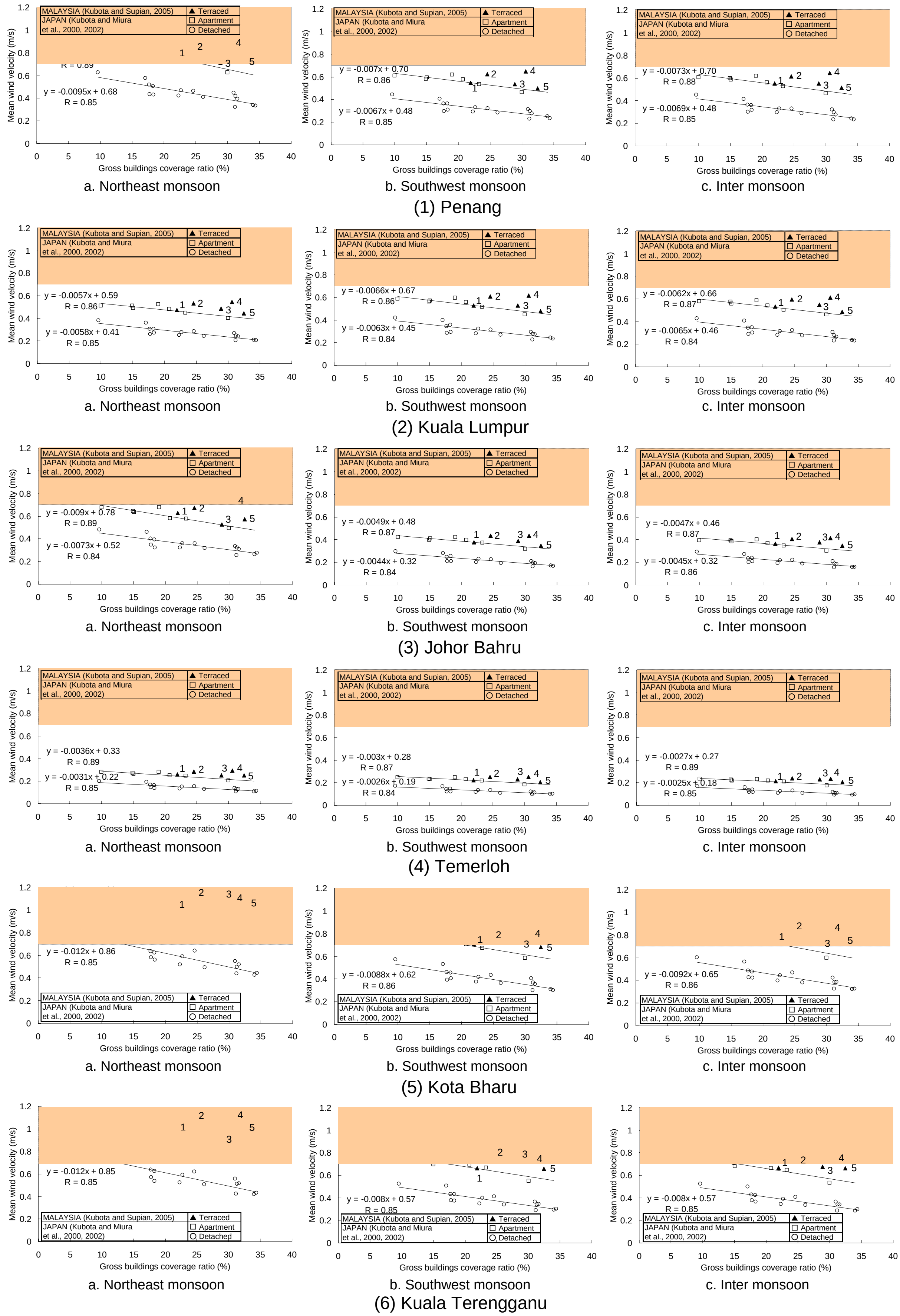
The effects of the northeast monsoon are relatively stronger than that of the southwest monsoon in Peninsular. This is mainly because of the geographical location of Sumatra Island of Indonesia (Fig.8). Especially on the east coast of Peninsular, this northeast monsoon strongly affects the regional climate. In addition, since the solar radiation in the tropics is very strong throughout the year, land-sea breeze is one of the most significant weather phenomena to affect the local climate particularly in coastal areas of Malaysia.

3.4. Results and discussion

The actual wind velocities at 1.5m height in all measuring points were calculated by using the above climatic data. The verifications of the methods had been made in the previous researches (Kubota and Miura et al., 2002). Fig.9 shows results of the calculations. Y-values in Fig.9 indicate the mean wind velocities of five terraced houses cases and Japanese cases under climatic conditions of respective six towns. Each plot in figures corresponds to the mean wind velocity for each case. For example, the mean wind velocity of case1 in Fig.9(1)-a was 0.79m/s. This means that the actual mean wind velocity of case1 will be 0.79m/s, if it is situated under climatic conditions of Penang during the northeast monsoon period. According to Murakami and Morikawa (1985), the wind velocity range of 0.7-1.7m/s allows a reasonable wind environment under daily mean temperature of more than 25˚C. These required reasonable wind velocity zones are indicated as hatch areas in Fig.9.

The weather station of Penang is located on the south coast of the Penang Island, facing the Strait of Malacca. In Penang, since the local mean wind velocity was relatively high during the northeast monsoon period, all five terraced houses cases are in required reasonable zone (Fig.9(1)-a). Nevertheless, both in the southwest monsoon period and the inter monsoon periods, the calculated mean wind velocities in all five cases do not meet required criterion (Fig.9(1)-bc). Yet the mean values of wind velocity ratio of five terraced houses cases had been higher than Japanese cases. The calculated mean wind velocities of five cases in both these periods range over 0.5-0.7m/s.

Kuala Lumpur is situated about 50km from the coastal line. In Kuala Lumpur, since the local mean wind velocity in the northeast monsoon period was lower than that of Penang, the calculated mean wind velocities in all five cases do not meet required criterion



Note: Hatch areas in figures indicate reasonable wind velocity zones proposed by Murakami and Morikawa (1985)

Fig.9. Results of wind environment evaluation in respective case study towns

throughout the year; the mean values range over 0.4-0.6m/s (Fig.9(2)). The results of Johor Bahru were similar with that of Kuala Lumpur. Except for case4 in the northeast monsoon period, the calculated mean wind velocities in all five cases do not meet required criterion throughout the year; the mean values range over 0.3-0.7m/s (Fig.9(3)). Temerloh, which is located in the inland, obtained much lower mean wind velocities. All five cases is far from the required reasonable zones throughout the year (Fig.9(4)). The calculated mean wind velocities of five cases range over 0.2-0.3m/s throughout the year.

The above results suggest that the terraced houses were one of the most typical housing types in Malaysia, but the calculated mean wind velocities in most terraced houses cases did not meet required criterion under respective climatic conditions in the east coast towns and inland town of Peninsular, except for the northeast monsoon period in Penang. This is mainly due to the weak wind conditions in these towns. It is considered that the location of towns, i.e. distance from the coastal line, has significant influence on such weak wind conditions.

Therefore, it can be concluded that generally the terraced houses areas may not be suitable for the towns located on the west coast and inland of Peninsular from a viewpoint of the wind flow at the neighborhood level. It is essential to consider the optimum location of towns for utilizing natural wind in neighborhood areas especially under weak wind conditions like the west coast and inland of Peninsular.

The local mean wind velocities in Kota Bharu and Kuala Terengganu were relatively higher throughout the year. Thus, the results of these towns show that many terraced houses cases are in required reasonable zones throughout the year. Especially during the northeast monsoon period, all five cases as well as Japanese apartment cases are in required reasonable zones as indicated in Fig.9(5)(6)-a. The calculated mean wind velocities in the northeast monsoon period of Kota Bharu and Kuala Terengganu indicate around 1.0-1.1m/s in respective five cases.

Therefore, although it has been considered that the terraced houses areas may not be suitable for the towns located on the west coast and inland of Peninsular, they may be acceptable especially for the towns located on the east coast of Peninsular from a viewpoint of the wind flow at the neighborhood level.

4. Conclusions

It is time for the countries in Southeast Asia to take concrete action in order to tackle global warming all over the world. The urban population has been rapidly increased in these countries. The current energy consumption in urban areas has become considerable high percentage and expected to further rise in the near future. Thus, it is essential to achieve the energy saving objectives in urban areas in every way. Moreover, we need to deal with the issue of world oil price hike by reducing the dependence on fossil fuels. Hence, the challenges for attaining energy efficient cities are strongly required for Southeast Asian countries. We have discussed throughout this paper the planning guidelines of neighborhood areas in consideration of wind flow in Malaysia. The summary of the findings is indicated as follows:

(1) Firstly, this paper reported results of a questionnaire survey on behavior for natural ventilation and electricity consumption among selected households in Johor Bahru City. The results showed 62% of respondents owned an average of 2.3 air-conditioners. It was implied that the air-conditioner ownership was expected to future rise according to continuing rise in household income in the near future. Moreover, the multiple regression analysis revealed that the reduction of both numbers and use of air-conditioners were the most effective means for achieving electricity saving among households.

(2) Further results showed the usage patterns of windows and air-conditioners did not overlap during the day regardless of the air-conditioner ownership. Therefore, it is very important to encourage both air-conditioner owners and non-owners to open their windows especially during the nighttime for achieving energy saving objectives. This

paper pointed out especially three suggestions, i.e. ‘insects screen’, ‘neighborhood security’ and ‘public awareness towards global environment’, which would encourage occupants to open their windows more and help achieve energy saving objectives in dwelling units.

(3) Secondly, this paper investigated physical wind environment in the same case study areas through wind tunnel tests. The results showed that generally the terraced houses areas might not be suitable for the towns on the west coast and inland of Peninsular Malaysia from a viewpoint of the wind flow at the neighborhood level. This was mainly due to the weak wind conditions in these towns. It was considered that the location of towns, i.e. distance from coastal line, had significant influences on such weak wind conditions. Therefore, it is essential to consider the optimum location of towns for utilizing natural wind in neighborhood areas especially under weak wind conditions like the west coast and inland of Peninsular Malaysia.

(4) A large number of mass residential areas have been developing in towns especially in the west coast of Peninsular Malaysia over the few decades, but they have not been taking account of wind flow. Further research is required to examine concrete planning methods to maintain a reasonable wind environment throughout the year especially under weak wind conditions. High-rise housing would be one of the effective means to utilize higher wind at the elevated floor level in urban Malaysia. It would promote natural ventilation and help achieve energy saving objectives in dwelling units.

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